NEW LIGHT ON TWO-ELECTRON JUMPS

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As is shown in preceding papers[1] the development of hot-spark spectroscopy, with the consequent opening up to precise measurement of a new spectral region, has for the first time given us a means of comparing the radiating properties of a long series of light atoms of like electronic structure such as is constituted by the seven "stripped atoms" from sodium through chlorine, viz., Na_{I}, Mg_{II}, Al_{III}, Si_{IV}, P_{V}, S_{VI}, Cl_{VII}.

A stripped atom is defined as an atom which has had all its valence electrons knocked off save the one whose jumps between the series of possible orbits give rise to the observed radiations. Stripped atoms may then be called one-valence-electron systems.

Such a series of one-valence-electron atoms as the foregoing in which the nuclear charge increases from 1 in the case of sodium to 7 in the case of chlorine has recently been shown to produce spectra which follow the X-ray spectral laws, namely the Moseley Law and the so-called "irregular doublet" law.[2]

By studying these spectra we have proved both experimentally and theoretically[3] that whenever a given type of spectral line is found to progress linearly with atomic number, i.e., whenever it is found to follow the irregular doublet law, the electron jumps giving rise to this line must all take place between orbits of the same total quantum number. *Only in this case is it possible for the observed frequencies to progress linearly with atomic number.*

By letting one more electron return to the last six of the stripped atoms mentioned above we obtain another series of atoms of like electronic structure which we have called a two-valence electron series, and similarly by letting still another electron come back to the last five of the above atoms we obtain another series of atoms of like electronic structure that we will call a three-valence-electron series.

We have recently made studies with the aid of our hot-spark spectrometry of the radiating properties of both two-valence-electron atoms and three-valence-electron atoms and have worked out the most important term values for many of them.[3] But in addition *we have found that there is one particular type of spectral flag that is flown by every one of the two-valence-electron systems with which we have worked, and that this appears to be a distinguishing, and easily recognizable characteristic of such a system.*

This flag consists of five nearly equally spaced bars or stripes the central one of which is about twice as heavy as the other four. It is seen standing

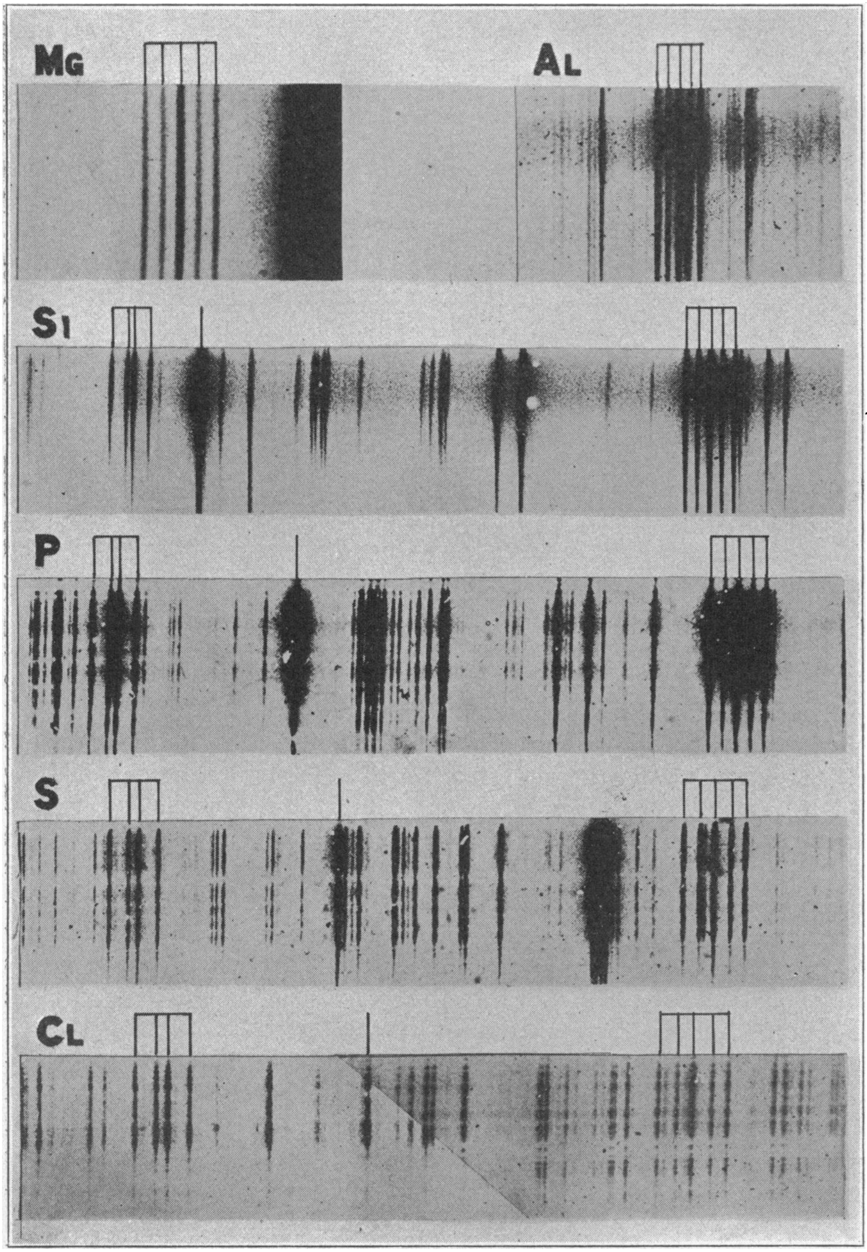

PLATE 1

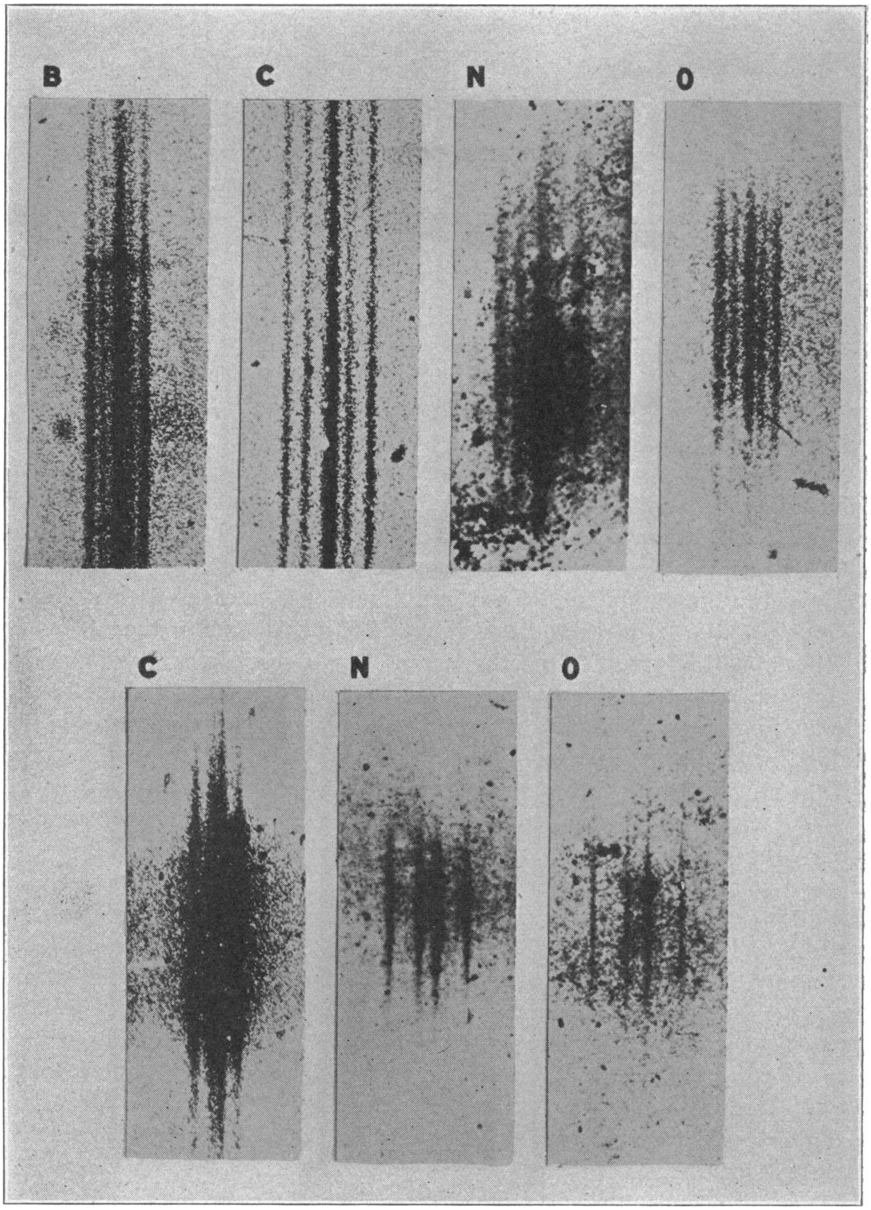

PLATE 2

out very conspicuously in two-valence-electron magnesium (Mg_I) in the upper left-hand corner of Plate 1, and on the right side of the same plate in two-valence-electron aluminum (Al_{II}), silicon (Si_{III}), phosphorus (P_{IV}), sulphur (S_V), and chlorine (Cl_{VI}). Also the upper half of Plate 2 reveals precisely the same flag in the spectra of two-valence-electron boron (B_{II}), carbon (C_{III}), nitrogen (N_{IV}), and oxygen (O_V).

Further, we have discovered that there is also a characteristic and easily recognizable flag that is flown by a three-valence-electron atom. This flag has never been observed before. It is strikingly shown along the left side of Plate 1 in the spectra of three-valence-electron silicon (Si_{II}), phosphorus (P_{III}), sulphur (S_{IV}), and chlorine (Cl_V), and in the lower half of Plate 2 in three-valence-electron carbon (C_{II}), nitrogen (N_{III}), and oxygen (O_{IV}). It consists of four bars the middle two of which are somewhat closer together than the distance from either to its outer neighbor.

Both of these flags can be definitely proved to be produced by the simultaneous jumping of two electrons, the observed frequencies being the sum of the changes in energy experienced by both of them together. Two years ago Wentzel[4] and Saunders and Russell[5] independently proved the existence of such double electron jumps in the calcium atom.

The corresponding proof is here found in the fact that the energy of the $3p_1$ term in aluminum is 48167.44 cm.$^{-1}$, while the measured energy (frequency) of the stronger and less refrangible middle line of the Al_I quadruplet is 56615.2 cm.$^{-1}$. In other words, the observed energy of the line is greater by 8448 frequency units than that corresponding to an electron jump from infinity into the p_1 level. This energy can then only be obtained from the simultaneous jumping of some other electron.

The precise nature of these two-electron jumps is here definitely revealed. *For since we find that both the quadruplet and the quintuplet groups show a very beautiful linear progression of frequency with atomic number, i.e., follow the irregular doublet law, they cannot involve any electron jump save such as takes the jumping electron or electrons between levels of the same total quantum number.* In the Be_I to O_V quintuplet series the jumps in question are definitely limited to jumps between these $2s$ and $2p$ levels, since there are no other levels of total quantum number 2. There can be little if any question then that *all of our observed two-electron jumps that produce the characteristic flags mentioned above consist in (1) a jump of one of the two electrons between a 2p and a 2s level, or a 3p and a 3s level, combined with a simultaneous jump of a second electron between two of the levels designated as* $2p_1$ $2p_2$ $2p_3$, *or* $3p_1$ $3p_2$ *and* $3p_3$.

The significance of this double electron jump is most easily seen in the case of the three-valence electron system. Such a system has normally two-valence electrons in s orbits and one in a p orbit. (See Fig. 1*A*.) When one of these s electrons absorbs energy and is pushed up to a p

orbit, the whole system of levels (orbits) about the nucleus changes because of the influence of the change in position of this electron upon the force-field about the nucleus, and the old p_1p_2 levels become displaced to the p_1^* p_2^* positions (see Fig. 1*B*). When now one of the electrons in a p^* orbit jumps back to its normal s position the other p electron has its p^* orbit knocked out from under it, so to speak, and it is obliged to jump back to one of the old p_1 p_2 positions simultaneously with the jump of the other p electron back to its s orbit. The four nearly equally intense lines of the quadruplet flag mean that in this enforced change of the electron

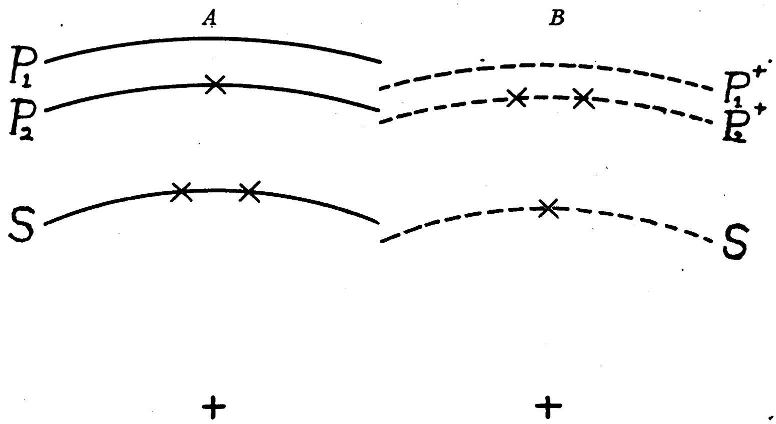

FIGURE 1

that remains in a p position it has about the same likelihood of starting from either one of the p_1^* p^* positions and landing in either one of the p_1 p_2 positions. These four nearly equal possibilities, each combined with the energy change corresponding to the p to s jump, produce the observed quadruplet. In the two-electron system there are three p levels and hence three p_2^* levels and hence six nearly equally intense lines, the two central ones overlapping and making thus the central line of double intensity characteristic of the quintuplet flag. A more detailed analysis of our results will soon appear in the *Physical Review*.

The foregoing shows very beautifully why the two-electron jumps must take place simultaneously. The fact that the energies of these two-electron jumps are added to produce a single monochromatic radiation of such frequency as is demanded by this summing-of-energy-principle raises very strikingly the question as to whether it is not forever impossible to find within an atom any single vibrating body whose frequency is that of the emitted wave. The mechanism of the transfer of energy between an atom and radiation does not seem to be of that sort. We are here in the presence of one of the most fundamental phenomena of the physical world.

[1] Bowen and Millikan, *Physic. Rev.*, **24,** 209 (1924), and **25,** 295 and **25,** 591 (1925); also *Nature*, **114,** 380 (1924).

[2] Millikan and Bowen, *Proc. Nat. Acad.*, **11,** 119 (1925).

[3] Bowen and Millikan, *Physic. Rev.*, **25,** 591 (1925).

[4] Wentzel, *Physic. Zeit.*, **24,** 106 (1923), and **25,** 182 (1924).

[5] Saunders and Russell, *Physic. Rev.*, **22,** 201 (1923), and *Astrophys. J.*, **61,** 38 (1925).

THE ANTI-STERILITY VITAMINE FAT SOLUBLE E[1]

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When rats are reared on various "synthetic" food mixtures consisting of fat, carbohydrate and protein in separate and relatively pure form together with an appropriate salt mixture and the vitamines A and B,[2] they grow well and have every appearance of health. Depending somewhat on the exact character and the proportions of the constituents of the food, they sooner or later exhibit complete sterility. In many instances a transitory period of fertility, variable in its length, follows the attainment of sexual maturity. This is usually the case with the male. But in the case of young from such females, secured either from their early fertility period or by fertility induced by certain food extracts hereinafter described, we usually observe complete sterility from the very beginning of sexual life. The sterility is a dietary deficiency disease for it can be cured or prevented by a change in dietary regime, a change involving the addition of certain single natural foods high in a new food factor, vitamine E,[3] or the addition of very much smaller amounts of extracts of those foods. The sterility disease affects males and females differently.

In the male it eventually leads to destruction of the germ cells (eventually the entire seminiferous epithelium) but this is not the case with the female, where the ovary and ovulation are unimpaired throughout life but where a highly characteristic disturbance occurs in gestation, the death and resorption of the developing young. It is necessary to insist on the peculiar character of dietary sterility thus produced in the female through lack of vitamine E, for it is only by ascertaining the existence of typical "resorption gestations" that one may be assured that he is dealing with deficiency in the specific substance E. Many other dietary delinquencies cause sterility in the female, but they all do so by interference with other steps in the reproductive mechanism than those involved in lack of E, usually by preventing oestrus, ovulation, fertilization or implantation but not by resorption after implantation has occurred. In order to establish